



INDIANA  
DEPARTMENT *of*  
EDUCATION

# 2023 INDIANA ACADEMIC STANDARDS **SCIENCE**

## EARTH & SPACE SCIENCE



## Indiana Academic Standards Context and Purpose

---

### Introduction

The Indiana Academic Standards for Earth and Space Science are the result of a process designed to identify, evaluate, synthesize, and create high-quality, rigorous learning expectations for Indiana students.

Pursuant to Indiana Code (IC) 20-31-3-1(c-d), the Indiana Department of Education (IDOE) facilitated the prioritization of the Indiana Academic Standards. All standards are required to be taught. Standards identified as essential for mastery by the end of the course are indicated with the word “Essential” under the standard number.

The Indiana Academic Standards are designed to ensure that all Indiana students, upon graduation, are prepared with essential knowledge and skills needed to access employment, enrollment, or enlistment leading to service.

### What are the Indiana Academic Standards and how should they be used?

The Indiana Academic Standards for Grades K-12 Science are based on *A Framework for K-12 Science Education* (NRC, 2012) and the Next Generation Science Standards (NGSS Lead States, 2013). The following conceptual shifts reflect what is new about these science standards. The Indiana Academic Standards for Science:

- Reflect science as it is practiced and experienced in the real world;
- Build logically from kindergarten through grade 12;
- Focus on deeper understanding as well as application of content; and
- Integrate practices, crosscutting concepts, and core ideas.

The K-12 Science Indiana Academic Standards outline the knowledge, science, and engineering practices that all students should learn by the end of high school. The standards are three-dimensional because each student performance expectation engages students at the nexus of the following three dimensions:

- **Dimension 1** describes scientific and engineering practices.
- **Dimension 2** describes crosscutting concepts, overarching science concepts that apply across science disciplines.
- **Dimension 3** describes core ideas in the science disciplines.

### Science and Engineering Practices (as found in NGSS)

The eight practices describe what scientists use to investigate and build models and theories of the world around them or that engineers use as they build and design systems. The practices are essential for all students to learn and are as follows:

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;

3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;
6. Constructing explanations for science and designing solutions for engineering;
7. Engaging in argument from evidence; and
8. Obtaining, evaluating, and communicating information.

### **Crosscutting Concepts** (*as found in NGSS*)

The seven crosscutting concepts bridge disciplinary boundaries and unit core ideas throughout the fields of science and engineering. Their purpose is to help students deepen their understanding of the disciplinary core ideas, and develop a coherent, and scientifically based view of the world. The seven crosscutting concepts are as follows:

1. *Patterns*. Observed patterns of forms and events guide organization and classification, and prompt questions about relationships and the factors that influence them.
2. *Cause and Effect: Mechanism and Explanation*. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.
3. *Scale, Proportion, and Quantity*. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.
4. *Systems and System Models*. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.
5. *Energy and Matter: Flows, Cycles, and Conservation*. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.
6. *Structure and Function*. The way in which an object or living thing is shaped and its substructure determines many of its properties and functions.
7. *Stability and Change*. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

### **Disciplinary Core Ideas** (*as found in NGSS*)

The disciplinary core ideas describe the content that occurs at each grade or course. The K-12 Science Indiana Academic Standards focus on a limited number of core ideas in science and engineering both within and across the disciplines and are built on the notion of learning as a developmental progression. The Disciplinary Core Ideas are grouped into the following domains:

- Physical Science (PS)
- Life Science (LS)
- Earth and Space Science (ESS)

- Engineering, Technology and Applications of Science (ETS)

While the Indiana Academic Standards establish key expectations for knowledge and skills and should be used as the basis for curriculum, the standards by themselves do not constitute a curriculum. It is the responsibility of the local school corporation to select and formally adopt curricular tools, including textbooks and any other supplementary materials, that align with Indiana Academic Standards. Additionally, corporation and school leaders should consider the appropriate instructional sequence of the standards as well as the length of time needed to teach each standard. Every standard has a unique place in the continuum of learning, but each standard will not require the same amount of time and attention. A deep understanding of the vertical articulation of the standards will enable educators to make the best instructional decisions. These standards must also be complemented by robust, evidence-based instructional practices to support overall student development. By utilizing strategic and intentional instructional practices, other areas such as STEM and employability skills can be integrated with the content standards.

## Acknowledgments

The Indiana Department of Education appreciates the time, dedication, and expertise offered by Indiana's K-12 educators, higher education professors, representatives from business and industry, families, and other stakeholders who contributed to the development of the Indiana Academic Standards. We wish to specially acknowledge the committee members, as well as participants in the public comment period, who dedicated many hours to the review and evaluation of these standards designed to prepare Indiana students for success after graduation.

## References

- National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/13165>.
- NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

## How to Read the Indiana Academic Standards for K-12 Science

Standard Number	Title	The title for a set of performance expectations is not necessarily unique and may be reused at several different grade levels.	
Students who demonstrate understanding can:			
Standard Number	Performance Expectation: A statement that combines practices, core ideas, and crosscutting concepts together to describe how students can show what they have learned. [Clarification Statement: A statement that supplies examples or additional clarification to the performance expectation.]		
Essential			
<div>Science and Engineering Practices</div> <p>Science and Engineering Practices are activities that scientists and engineers engage in to either understand the world or solve the problem.</p> <p>There are 8 practices. These are integrated into each standard. They were previously found at the beginning of each grade level content standard and known as SEPs.</p> <p><b>Connections to the Nature of Science</b></p> <p>Connections are listed in either practices or the crosscutting concepts section.</p>		<div>Disciplinary Core Ideas</div> <p>Disciplinary Core Ideas are concepts in science and engineering that have broad importance within and across disciplines as well as relevance in people's lives.</p> <p>To be considered core, the ideas should meet at least two of the following criteria and ideally all four:</p> <ul style="list-style-type: none"><li>• Have broad importance across multiple sciences or engineering disciplines or be a key organizing concept of a single discipline.</li><li>• Provide a key tool for understanding or investigating more complex ideas and solving problems.</li><li>• Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.</li><li>• Be teachable and learnable over multiple grades at increasing levels of depth and sophistication.</li></ul> <p>Disciplinary ideas are grouped in four domains: the physical sciences; the life sciences; the earth and space sciences; and engineering, technology, and applications of science.</p> <p>Disciplinary ideas are grouped in four domains: the physical sciences; the life sciences; the earth and space sciences; and engineering, technology, and applications of science.</p> <p>A disciplinary core idea is identified as “(secondary)” when the other featured disciplinary core ideas connect to the science and engineering practices and crosscutting concepts as the main focus of the performance expectation.</p>	
		<div>Crosscutting Concepts</div> <p>Crosscutting concepts are seven ideas such as Patterns and Cause and Effect, which are not specific to any one discipline but cut across them all.</p> <p>Crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas.</p> <p><b>Connections to Engineering, Technology and Applications of Science</b></p> <ul style="list-style-type: none"><li>• These connections are drawn from either the Disciplinary Core Ideas or Science and Engineering Practices.</li></ul>	

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

<b>HS-ESS1-1 Earth's Place in the Universe</b>	
Students who demonstrate understanding can:	
<b>HS-ESS1-1</b> <b>Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.</b> <b>Essential</b> [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.]	
<b>Science and Engineering Practices</b> <b>SEP.2: Developing and Using Models</b> Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). <ul style="list-style-type: none"> <li>Develop a model based on evidence to illustrate the relationships between systems or between components of a system.</li> </ul>	<b>Disciplinary Core Ideas</b> <b>ESS1.A: The Universe and Its Stars</b> <ul style="list-style-type: none"> <li>The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.</li> </ul> <b>PS3.D: Energy in Chemical Processes and Everyday Life</b> <ul style="list-style-type: none"> <li>Nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. (<i>secondary</i>)</li> </ul>
	<b>Crosscutting Concepts</b> <b>CC.3: Scale, Proportion, and Quantity</b> <ul style="list-style-type: none"> <li>The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.</li> </ul>

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

<b>HS-ESS1-2 Earth's Place in the Universe</b>	
<p>Students who demonstrate understanding can:</p> <p><b>HS-ESS1-2 Construct an explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.</b>  [Clarification Statement: Emphasis is on the astronomical evidence of the red shift of light from galaxies as an indication that the universe is currently expanding, the cosmic microwave background as the remnant radiation from the Big Bang, and the observed composition of ordinary matter of the universe, primarily found in stars and interstellar gases (from the spectra of electromagnetic radiation from stars), which matches that predicted by the Big Bang theory (3/4 hydrogen and 1/4 helium).]</p>	
<p><b>Science and Engineering Practices</b></p> <p><b>SEP.6: Constructing Explanations and Designing Solutions</b></p> <p>Constructing explanations and designing solutions in 9-12 builds on K-8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> <li>Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.</li> </ul> <p>-----</p> <p><b>Connections to Nature of Science</b></p> <p><b>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</b></p> <ul style="list-style-type: none"> <li>A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.</li> </ul>	<p><b>Disciplinary Core Ideas</b></p> <p><b>ESS1.A: The Universe and Its Stars</b></p> <ul style="list-style-type: none"> <li>The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.</li> <li>The Big Bang theory is supported by observations of distant galaxies receding from our own, of the measured composition of stars and non-stellar gases, and of the maps of spectra of the primordial radiation (cosmic microwave background) that still fills the universe.</li> <li>Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.</li> </ul> <p><b>PS4.B: Electromagnetic Radiation</b></p> <ul style="list-style-type: none"> <li>Atoms of each element emit and absorb characteristic frequencies of light. These characteristics allow identification of the presence of an element, even in microscopic quantities. (secondary)</li> </ul> <p><b>Crosscutting Concepts</b></p> <p><b>CC.5: Energy and Matter</b></p> <ul style="list-style-type: none"> <li>Energy cannot be created or destroyed—only moved between one place and another place, between objects and/or fields, or between systems.</li> </ul> <p>-----</p> <p><b>Connections to Engineering, Technology, and Applications of Science</b></p> <p><b>Interdependence of Science, Engineering, and Technology</b></p> <ul style="list-style-type: none"> <li>Science and engineering complement each other in the cycle known as research and development (R&amp;D). Many R&amp;D projects may involve scientists, engineers, and others with wide ranges of expertise.</li> </ul> <p>-----</p>

	<p style="text-align: center;"><b><i>Connections to Nature of Science</i></b></p> <p><b>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</b></p> <ul style="list-style-type: none"><li>• Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future.</li><li>• Science assumes the universe is a vast single system in which basic laws are consistent.</li></ul>
--	--

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.



<b>HS-ESS1-3 Earth's Place in the Universe</b>	
Students who demonstrate understanding can:	
<b>HS-ESS1-3 Communicate scientific ideas about the way stars, over their life cycle, produce elements.</b> [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.]	
The performance expectation above was developed using the following elements from <i>A Framework for K-12 Science Education</i> .	
<b>Science and Engineering Practices</b>  <b>SEP.8: Obtaining, Evaluating, and Communicating Information</b>  Obtaining, evaluating, and communicating information in 9-12 builds on K-8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. <ul style="list-style-type: none"> <li>Communicate scientific ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).</li> </ul>	<b>Disciplinary Core Ideas</b>  <b>ESS1.A: The Universe and Its Stars</b> <ul style="list-style-type: none"> <li>The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.</li> <li>Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.</li> </ul>
	<b>Crosscutting Concepts</b>  <b>CC.5: Energy and Matter</b> <ul style="list-style-type: none"> <li>In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.</li> </ul>

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

<b>HS-ESS1-4 Earth's Place in the Universe</b>	
<p>Students who demonstrate understanding can:</p> <p><b>HS-ESS1-4 Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.</b> [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.]</p>	
<p><b>Science and Engineering Practices</b></p> <p><b>SEP.5: Using Mathematical and Computational Thinking</b></p> <p>Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> <li>Use mathematical or computational representations of phenomena to describe explanations.</li> </ul>	<p><b>Disciplinary Core Ideas</b></p> <p><b>ESS1.B: Earth and the Solar System</b></p> <ul style="list-style-type: none"> <li>Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.</li> </ul> <p><b>Crosscutting Concepts</b></p> <p><b>CC.3: Scale, Proportion, and Quantity</b></p> <ul style="list-style-type: none"> <li>Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).</li> </ul> <p>-----</p> <p><b>Connections to Engineering, Technology, and Applications of Science</b></p> <p><b>Interdependence of Science, Engineering, and Technology</b></p> <ul style="list-style-type: none"> <li>Science and engineering complement each other in the cycle known as research and development (R&amp;D). Many R&amp;D projects may involve scientists, engineers, and others with wide ranges of expertise.</li> </ul>

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS1-5 Earth's Place in the Universe**

Students who demonstrate understanding can:

**HS-ESS1-5 Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.** [Clarification Statement:

**Essential**

Emphasis is on the ability of plate tectonics to explain the ages of crustal rocks. Examples include evidence of the ages of oceanic crust increasing with distance from mid-ocean ridges (a result of plate spreading) and the ages of North American continental crust decreasing with distance away from a central ancient core of the continental plate (a result of past plate interactions).]

**Science and Engineering Practices****SEP.7: Engaging in Argument from Evidence**

Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate evidence behind currently accepted explanations or solutions to determine the merits of arguments.

**Disciplinary Core Ideas****ESS1.C: The History of Planet Earth**

- Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old.

**ESS2.B: Plate Tectonics and Large-Scale System Interactions**

- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. (secondary)

**PS1.C: Nuclear Processes**

- Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (secondary)

**Crosscutting Concepts****CC.1: Patterns**

- Empirical evidence is needed to identify patterns.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS1-6 Earth's Place in the Universe**

Students who demonstrate understanding can:

- HS-ESS1-6** Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.
- Essential** [Clarification Statement: Emphasis is on using available evidence within the solar system to reconstruct the early history of Earth, which formed along with the rest of the solar system 4.6 billion years ago. Examples of evidence include the absolute ages of ancient materials (obtained by radiometric dating of meteorites, moon rocks, and Earth's oldest minerals), the sizes and compositions of solar system objects, and the impact cratering record of planetary surfaces.]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*.

Science and Engineering Practices	Disciplinary Core Ideas
<p><b>SEP.6: Constructing Explanations and Designing Solutions</b></p> <p>Constructing explanations and designing solutions in 9-12 builds on K-8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> <li>Apply scientific reasoning to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.</li> </ul> <p>-----</p> <p><b>Connections to Nature of Science</b></p> <p><b>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena</b></p> <ul style="list-style-type: none"> <li>A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.</li> <li>Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory.</li> </ul>	<p><b>ESS1.C: The History of Planet Earth</b></p> <ul style="list-style-type: none"> <li>Although active geologic processes, such as plate tectonics and erosion, have destroyed or altered most of the very early rock record on Earth, other objects in the solar system, such as lunar rocks, asteroids, and meteorites, have changed little over billions of years. Studying these objects can provide information about Earth's formation and early history.</li> </ul> <p><b>PS1.C: Nuclear Processes</b></p> <ul style="list-style-type: none"> <li>Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks and other materials. (<i>secondary</i>)</li> </ul>
	Crosscutting Concepts
	<p><b>CC.7: Stability and Change</b></p> <ul style="list-style-type: none"> <li>Much of science deals with constructing explanations of how things change and how they remain stable.</li> </ul>

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS2-1 Earth's Systems**

Students who demonstrate understanding can:

- HS-ESS2-1**     **Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.**  
 [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).]

**Science and Engineering Practices**
**SEP.2: Developing and Using Models**

Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

**Disciplinary Core Ideas**
**ESS2.A: Earth Materials and Systems**

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

**ESS2.B: Plate Tectonics and Large-Scale System Interactions**

- Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. Plate movements are responsible for most continental and ocean-floor features and for the distribution of most rocks and minerals within Earth's crust.

**Crosscutting Concepts**
**CC.7: Stability and Change**

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS2-2 Earth's Systems**

Students who demonstrate understanding can:

- HS-ESS2-2** **Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.** [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]
- Essential**

**Science and Engineering Practices****SEP.4: Analyzing and Interpreting Data**

Analyzing data in 9-12 builds on K-8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

**Disciplinary Core Ideas****ESS2.A: Earth Materials and Systems**

- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

**ESS2.D: Weather and Climate**

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

**Crosscutting Concepts****CC.7: Stability and Change**

- Feedback (negative or positive) can stabilize or destabilize a system.

-----

**Connections to Engineering, Technology, and Applications of Science**

**Influence of Engineering, Technology, and Science on Society and the Natural World**

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS2-3 Earth's Systems**

Students who demonstrate understanding can:

- HS-ESS2-3**    **Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.** [Clarification Statement: Emphasis is on both a one-dimensional model of Earth, with radial layers determined by density, and a three-dimensional model, which is controlled by mantle convection and the resulting plate tectonics. Examples of evidence include maps of Earth's three-dimensional structure obtained from seismic waves, records of the rate of change of Earth's magnetic field (as constraints on convection in the outer core), and identification of the composition of Earth's layers from high-pressure laboratory experiments.]

**Science and Engineering Practices****SEP.2: Developing and Using Models**

Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

-----

**Connections to Nature of Science**

**Scientific Knowledge is Based on Empirical Evidence**

- Science knowledge is based on empirical evidence.
- Science disciplines share common rules of evidence used to evaluate explanations about natural systems.
- Science includes the process of coordinating patterns of evidence with current theory.

**Disciplinary Core Ideas****ESS2.A: Earth Materials and Systems**

- Evidence from deep probes and seismic waves, reconstructions of historical changes in Earth's surface and its magnetic field, and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior.

**ESS2.B: Plate Tectonics and Large-Scale System Interactions**

- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection.

**PS4.A: Wave Properties**

- Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. (secondary)

**Crosscutting Concepts****CC.5: Energy and Matter**

- Energy drives the cycling of matter within and between systems.

-----

**Connections to Engineering, Technology, and Applications of Science**

**Interdependence of Science, Engineering, and Technology**

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS2-4 Earth's Systems**

Students who demonstrate understanding can:

**HS-ESS2-4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.** [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.]

### Science and Engineering Practices

#### SEP.2: Developing and Using Models

Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Use a model to provide mechanistic accounts of phenomena.

#### Connections to Nature of Science

#### Scientific Knowledge is Based on Empirical Evidence

- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

### Disciplinary Core Ideas

#### ESS1.B: Earth and the Solar System

- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. (*secondary*)

#### ESS2.A: Earth Materials and Systems

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.

#### ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space.

### Crosscutting Concepts

#### CC.2: Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.



**HS-ESS2-5 Earth's Systems**

Students who demonstrate understanding can:

**HS-ESS2-5** **Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes.** [Clarification Statement: Emphasis is on mechanical and chemical investigations with water and a variety of solid materials to provide the evidence for connections between the hydrologic cycle and system interactions commonly known as the rock cycle. Examples of mechanical investigations include stream transportation and deposition using a stream table, erosion using variations in soil moisture content, or frost wedging by the expansion of water as it freezes. Examples of chemical investigations include chemical weathering and recrystallization (by testing the solubility of different materials) or melt generation (by examining how water lowers the melting temperature of most solids).]

**Essential**

**Science and Engineering Practices****SEP.3: Planning and Carrying Out Investigations**

Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

**Disciplinary Core Ideas****ESS2.C: The Roles of Water in Earth's Surface Processes**

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.

**Crosscutting Concepts****CC.6: Structure and Function**

- The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS2-6 Earth's Systems**

Students who demonstrate understanding can:

**HS-ESS2-6**    **Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.** [Clarification Statement: Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

**Science and Engineering Practices**
**SEP.2: Developing and Using Models**

Modeling in 9-12 builds on K-8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

**Disciplinary Core Ideas**
**ESS2.D: Weather and Climate**

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

**Crosscutting Concepts**
**CC.5: Energy and Matter**

- The total amount of energy and matter in closed systems is conserved.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS2-7 Earth's Systems**

Students who demonstrate understanding can:

**HS-ESS2-7 Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.]

### Science and Engineering Practices

#### SEP.7: Engaging in Argument from Evidence

Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Construct an oral and written argument or counter-arguments based on data and evidence.

### Disciplinary Core Ideas

#### ESS2.D: Weather and Climate

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.

#### ESS2.E Biogeology

- The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it.

### Crosscutting Concepts

#### CC.7: Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS3-1 Earth and Human Activity**

Students who demonstrate understanding can:

**HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.**

**Essential**

[Clarification Statement: Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.]

**Science and Engineering Practices****SEP.6: Constructing Explanations and Designing Solutions**

Constructing explanations and designing solutions in 9-12 builds on K-8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories.

- Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

**Disciplinary Core Ideas****ESS3.A: Natural Resources**

- Resource availability has guided the development of human society.

**ESS3.B: Natural Hazards**

- Natural hazards and other geologic events have shaped the course of human history; [they] have significantly altered the sizes of human populations and have driven human migrations.

**Crosscutting Concepts****CC.2: Cause and Effect**

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

-----

***Connections to Engineering, Technology, and Applications of Science***

**Influence of Science, Engineering, and Technology on Society and the Natural World**

- Modern civilization depends on major technological systems.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS3-2 Earth and Human Activity**

Students who demonstrate understanding can:

- HS-ESS3-2 Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.** [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

**Science and Engineering Practices****SEP.7: Engaging in Argument from Evidence**

Engaging in argument from evidence in 9-12 builds on K-8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

**Disciplinary Core Ideas****ESS3.A: Natural Resources**

- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

**ETS1.B: Developing Possible Solutions**

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (*secondary*)

**Crosscutting Concepts****Connections to Engineering, Technology, and Applications of Science****Influence of Science, Engineering, and Technology on Society and the Natural World**

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.
- Analysis of costs and benefits is a critical aspect of decisions about technology.

**Connections to Nature of Science****Science Addresses Questions About the Natural and Material World**

- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Science knowledge indicates what can happen in natural systems — not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- Many decisions are not made using science alone but rely on social and cultural contexts to resolve issues.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS3-3 Earth and Human Activity**

Students who demonstrate understanding can:

- HS-ESS3-3** Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity. [Clarification Statement: Examples of factors that affect the management of natural resources include costs of resource extraction and waste management, per-capita consumption, and the development of new technologies. Examples of factors that affect human sustainability include agricultural efficiency, levels of conservation, and urban planning.]

**Science and Engineering Practices****SEP.5: Using Mathematics and Computational Thinking**

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials, and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

**Disciplinary Core Ideas****ESS3.C: Human Impacts on Earth Systems**

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.

**Crosscutting Concepts****CC.7: Stability and Change**

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

-----

**Connections to Engineering, Technology, and Applications of Science**

**Influence of Science, Engineering, and Technology on Society and the Natural World**

- Modern civilization depends on major technological systems.
- New technologies can have deep impacts on society and the environment, including some that were not anticipated.

-----

**Connections to Nature of Science**

**Science is a Human Endeavor**

- Science is a result of human endeavors, imagination, and creativity.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

<b>HS-ESS3-4 Earth and Human Activity</b>	
Students who demonstrate understanding can:	
<b>HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.</b> [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]	
<b>Science and Engineering Practices</b> <b>SEP.6: Constructing Explanations and Designing Solutions</b> Constructing explanations and designing solutions in 9-12 builds on K-8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories. <ul style="list-style-type: none"> <li>Design or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</li> </ul>	<b>Disciplinary Core Ideas</b> <b>ESS3.C: Human Impacts on Earth Systems</b> <ul style="list-style-type: none"> <li>Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.</li> </ul> <b>ETS1.B: Developing Possible Solutions</b> <ul style="list-style-type: none"> <li>When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (<i>secondary</i>)</li> </ul>
	<b>Crosscutting Concepts</b> <b>CC.7: Stability and Change</b> <ul style="list-style-type: none"> <li>Feedback (negative or positive) can stabilize or destabilize a system.</li> </ul> <p>-----</p> <p><b>Connections to Engineering, Technology, and Applications of Science</b></p> <p><b>Influence of Science, Engineering, and Technology on Society and the Natural World</b></p> <ul style="list-style-type: none"> <li>Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.</li> </ul>

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.

**HS-ESS3-5 Earth and Human Activity**

Students who demonstrate understanding can:

**HS-ESS3-5** **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).]

**Essential****Science and Engineering Practices****SEP.4: Analyzing and Interpreting Data**

Analyzing data in 9-12 builds on K-8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using computational models in order to make valid and reliable scientific claims.

-----

**Connections to Nature of Science****Scientific Investigations Use a Variety of Methods**

- Science investigations use diverse methods and do not always use the same set of procedures to obtain data.
- New technologies advance scientific knowledge.

**Scientific Knowledge is Based on Empirical Evidence**

- Science knowledge is based on empirical evidence.
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

**Disciplinary Core Ideas****ESS3.D: Global Climate Change**

- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.

**Crosscutting Concepts****CC.7: Stability and Change**

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.



**HS-ESS3-6 Earth and Human Activity**

Students who demonstrate understanding can:

- HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.** [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.]

**Science and Engineering Practices****SEP.5: Using Mathematics and Computational Thinking**

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis; a range of linear and nonlinear functions including trigonometric functions, exponentials, and logarithms; and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations.

**Disciplinary Core Ideas****ESS2.D: Weather and Climate**

- Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. (*secondary*)

**ESS3.D: Global Climate Change**

- Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.

**Crosscutting Concepts****CC.4: Systems and System Models**

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

**Note:** Performance Expectations, Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts appear as defined in the Next Generation Science Standards.